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16. ABSTRACT

Recent investigations of surface water and precipitation chemistry have aroused considerable concern about the potential effects of acidic precipitation on aquatic ecosystems in the north-central United States. The mean weighted pH of precipitation at two monitoring stations in north-central Wisconsin during 1980 was 4.45 and 4.63 [7], or about 10-14 times more acidic than "normal" rainfall, which has a theoretical pH of 5.6 [8]. Many watersheds in northern Wisconsin have acid soils with low buffering capacity [9]. Consequently, the water of most lakes in these watersheds is very soft and slightly acidic. Analyses of 275 northern Wisconsin lakes by Eilers et al. [10] during 1979 indicated that 36% of the lakes were susceptible and an additional 50% were potentially susceptible to acidification from acid precipitation, as judged by the calcite saturation index [11], and that hydrologic type was the major factor affecting susceptibility.

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CHAPTER 8

Species Composition of Fish Communities in Northern Wisconsin Lakes: Relation to pH*

James G. Wiener
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Joseph M. Eilers

Acidification of surface waters in Scandinavian countries and eastern North America, coincident with increases in the acidity of precipitation, has had pronounced adverse effects on fishes and other aquatic biota [1]. Valuable fishery resources have been lost in these regions [2–6], and such losses may become more widespread if acidic precipitation continues. The decline of fish populations in acidified lakes has generally been associated with reproductive failure, rather than with mortality of adult fish [1].

Recent investigations of surface water and precipitation chemistry have aroused considerable concern about the potential effects of acidic precipitation on aquatic ecosystems in the north-central United States. The mean weighted pH of precipitation at two monitoring stations in north-central Wisconsin during 1980 was 4.45 and 4.63 [7], or about 10–14 times more acidic than "normal" rainfall, which has a theoretical pH of 5.6 [8]. Many watersheds in northern Wisconsin have acid soils with low buffering capacity [9]. Consequently, the water of most lakes in these watersheds is very soft and slightly acidic. Analyses of 275 northern Wisconsin lakes by Eilers et al. [10] during 1979 indicated that 36% of the lakes were susceptible and an additional 50% were potentially susceptible to acidification from acid precipitation, as judged by the calcite saturation index [11], and that hydrologic type was the major factor affecting susceptibility. Drained lakes (having no inlet and an intermittent outlet) and seepage lakes (having no inlets or outlets) were most sensitive to acidification because their dissolved mineral content was

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low and they were influenced little by groundwater. Continuing inputs of acidic precipitation to these poorly buffered lakes could result in a depletion of the buffer system and eventual acidification [12].

This chapter compares species composition and richness of fish communities in two groups of clearwater lakes in north-central Wisconsin: (1) six lakes with pH 5.1–6.0 (here termed acidic) and (2) six lakes with pH 6.7–7.5 (here termed circumneutral). Differences in the fish communities between the two groups of lakes are statistically compared and discussed in terms of pH-related effects; however, many water chemistry parameters (e.g., alkalinity, metal concentrations and Ca^{2+}) vary concomitantly with pH. We emphasize that the acidic and circumneutral lakes differ mainly in pH-related chemical characteristics and not solely in pH.

STUDY AREA

Study lakes were selected to ensure that confounding effects due to differences between the two lake groups in factors such as morphology, hydrology and natural immigration or emigration of fishes were minimized. The following criteria were used for selection of lakes for study:

1. include only seepage and drained lakes;
2. avoid dystrophic (based on water color), winterkill and atypical lakes (e.g., unusually large or deep lakes), and lakes in recently disturbed watersheds;
3. avoid lakes with watershed-area-to-lake-area ratios outside the range of 2–10; and
4. rank and select 12 lakes according to the availability of historical fisheries and water chemistry data.

Six lakes were naturally acidic and susceptible to cultural acidification and six were circumneutral and well buffered (Figure 1 and Table I). Ten of the lakes are seepage lakes, and two—Hixon (circumneutral) and Clara (acidic)—are drained by intermittent outlets. One lake (Flannery) is connected to another small seepage lake (not studied) by a permanent channel. Natural migrations of fish to and from the 12 lakes are considered to be negligible. The two groups of lakes were morphologically similar, but differed substantially in pH, alkalinity and related chemical characteristics (Table I). The distribution of substrate types did not differ greatly between the acidic and circumneutral lakes. In the acidic lakes, the percent muck, sand, gravel, and rock and rubble ranged from 5–45, 25–70, 10–35 and 0–25, respectively; the percentages were 0–35, 60–75, 5–25 and 0–10, respectively, in the circumneutral lakes [13–15].

The occurrence of numerous naturally acidic lakes in northern Wisconsin was documented nearly 50 years ago [16]. Bowser [17] compared the current pH, alkalinity and conductivity of a number of northern Wisconsin lakes to values recorded for those lakes half a century ago by Birge, Juday and their co-workers and found no evidence of recent cultural acidification. On the basis of these findings, we assume that the acidic lakes studied here are naturally acidic.

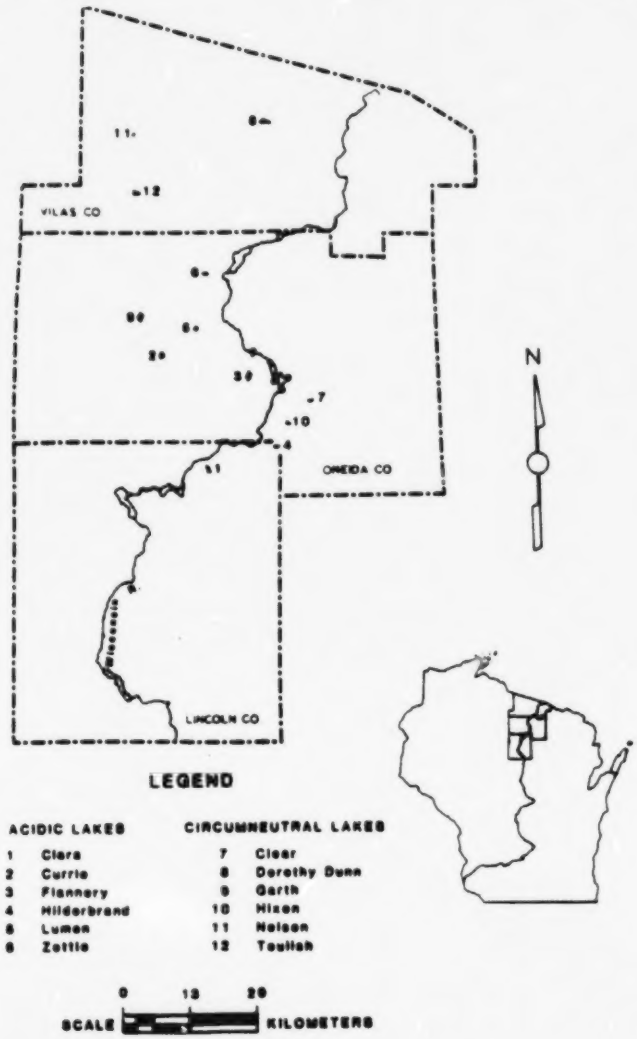

Figure 1. Locations of the 12 Wisconsin lakes that were studied.

METHODS

Fish sampling was begun on July 8 and completed on August 20, 1980. Fish were collected with gill nets, fyke nets, minnow traps and seines. A standard sampling protocol was followed and yielded equal sampling effort on each lake,

Table I. Characteristics of Wisconsin Lakes in Which Fish Communities Were Studied

Lake Category and Name	*Surface Area (ha)*	*Watershed-to-Lake Area Ratio*	*SDI*[a]	*Maximum Depth (m)*	*Mean Depth (m)*	*pH*[b]	*Alkalinity*[b] *($\mu eq \cdot L^{-1}$)*	*Specific*[b] *Conductance ($\mu mho \cdot cm^{-1}$ at 25 C)*	*Secchi Disk Visibility*[c] *(m)*	*Apparent Color*[d] *(Pt-Co Units)*
Acidic										
Clara	34.1	4.9	1.76	11.4	5.1	6.0	28	36	4.2	7.5
Curne	39.0	3.8	1.31	4.3	1.9	5.6	6	16	2.3	20
Flannery[e]	45.3	2.2	2.50	10.6	6.3	5.7	6	23	3.8	2.5
Hilderbrand	24.2	4.8	1.21	8.0	4.2	5.1	3	23	3.9	12.5
Lumen	19.8	2.5	1.43	7.2	3.7	5.2	−5	21	3.9	7.5
Zottle	11.4	5.1	1.48	11.6	4.3	5.6	16	19	4.3	7.5
Mean	29.0	3.9	1.6	8.9	4.3	5.5	9	23	3.7	9.6
Range	11.4–45.3	2.2–5.1	1.2–2.5	4.3–11.6	1.9–6.3	5.1–6.0	−5–28	16–36	2.3–4.3	2.5–20
Circumneutral										
Clear	14.7	2.8	1.31	7.3	2.4	6.9	400	98	1.0	10
Dorothy Dunn	28.3	3.0	1.80	8.2	2.7	6.9	312	39	3.1	7.5
Garth	46.2	2.3	1.20	6.7	3.7	7.5	764	70	2.4	12.5
Hixon	20.2	7.6	1.82	8.5	3.1	6.8	340	47	1.5	40
Nelson	10.9	4.7	1.10	15.8	6.7	7.0	342	42	2.9	7.5
Toulish	32.0	2.3	1.50	11.0	5.5	6.7	402	47	2.8	10
Mean	25.4	3.8	1.5	9.6	4.0	7.0	427	57	2.3	14.6
Range	10.9–46.2	2.3–7.6	1.1–1.8	6.7–15.8	2.4–6.7	6.7–7.5	312–764	39–98	1.0–3.1	7.5–40

[a] Shoreline development factor.

[b] Means of samples collected at 0.5 m below surface, middepth, and 0.5 m above bottom after the autumnal overturn (October 1981). Mean pH given for each lake was calculated from the mean hydrogen ion concentration.

[c] Measured during the October 1981 sampling period.

[d] Samples collected at 0.5 m below surface during June 1982.

[e] Flannery Lake is joined by a channel to another seepage lake (Velvet Lake, 14.2 ha), which was not sampled.

Table II. Summary of Sampling Effort for Characterizing Fish Communities in Study Lakes

Type of Gear	*Effort per Lake*
300-ft (91.4-m), variable mesh gill net	4 nets for 2 nights[a]
Small mesh (3/8-in. or 0.95-cm) fyke net	7 nets for 2 nights[a]
Minnow trap (1/4-in. or 0.64-cm mesh)	10 traps for 2 nights[a]
25-ft bag seine with 3/16-in. (0.48-cm) mesh in bag	25 seine hauls

[a] Fish removed daily.

with only minor exceptions (Table II). Minnows were identified according to Becker and Johnson [18].

Water samples were collected during the fish sampling period and analyzed for pH and alkalinity; however, later analyses indicated that pH readings obtained with the field meter being used at that time were inaccurate. Subsequent water sampling was conducted on all 12 lakes during October 1981, after the autumnal overturn, when lakes were completely mixed. Water samples from each lake were collected near the point of maximum depth at 0.5 m below surface, middepth and 0.5 m above bottom. Differences in water temperature between points 0.5 m below surface and 0.5 m above bottom for the 12 lakes averaged 0.2 C and ranged from 0.0 to 0.5 C during this sampling period. The pH of the October 1981 samples was measured with an Orion model 407A meter, total alkalinity by Gran titration [19] and specific conductance with a YSI model 32 conductivity meter. Mean pH of each lake was calculated as the negative logarithm of the average hydrogen ion concentration over depths. Apparent color (unfiltered water samples) was measured with a Hellige model 611-A Aqua Tester. Apparent and true color of water from northern Wisconsin lakes are similar [10]. Data analyses were conducted with the Michigan Interactive Data Analysis System (MIDAS) at the University of Michigan [20].

RESULTS AND DISCUSSION

A total of 30,388 fish, representing 27 species and 10 families (Table III), were collected during the fishery survey of the 12 lakes. The number of fish collected from individual lakes ranged from 1141 to 9234 (Table IV). Fish communities in the lakes were dominated largely by members of the sunfish family (Centrarchidae) and perch family (Percidae) (Table V). Only two species, largemouth bass and yellow perch, were found in all 12 lakes (Table VI).

Table III. Common and Scientific Names of 27 Species of Fish Collected in Northern Wisconsin Study Lakes (Nomenclature Follows Robins et al. [21]).

Family	*Common Name*	*Scientific Name*
Salmonidae	Cisco	*Coregonus artedii*
Umbridae	Central mudminnow	*Umbra limi*
Esocidae	Northern pike	*Esox lucius*
	Muskellunge	*Esox masquinongy*
Cyprinidae	Golden shiner	*Notemigonus crysoleucas*
	Blackchin shiner	*Notropis heterodon*
	Blacknose shiner	*Notropis heterolepis*
	Emerald shiner	*Notropis atherinoides*
	Weed shiner	*Notropis texanus*
	Bluntnose minnow	*Pimephales notatus*
	Creek chub	*Semotilus atromaculatus*
Catostomidae	White sucker	*Catostomus commersoni*
Ictaluridae	Black bullhead	*Ictalurus melas*
	Yellow bullhead	*Ictalurus natalis*
Gasterosteidae	Brook stickleback	*Culaea inconstans*
Centrarchidae	Rock bass	*Ambloplites rupestris*
	Green sunfish	*Lepomis cyanellus*
	Pumpkinseed	*Lepomis gibbosus*
	Bluegill	*Lepomis macrochirus*
	Smallmouth bass	*Micropterus dolomieui*
	Largemouth bass	*Micropterus salmoides*
	Black crappie	*Pomoxis nigromaculatus*
Percidae	Iowa darter	*Etheostoma exile*
	Johnny darter	*Etheostoma nigrum*
	Yellow perch	*Perca flavescens*
	Walleye	*Stizostedion vitreum vitreum*
Cottidae	Mottled sculpin	*Cottus bairdi*

Species richness (number of fish species) was lower in the acidic lakes than in the circumneutral lakes. A total 15 species were collected in the six acidic lakes, and 25 species were found in the circumneutral lakes (Tables V and VI). Species richness ranged from 5 to 11 in the acidic lakes and from 10 to 17 in the circumneutral lakes (Table IV). A Mann–Whitney test indicated that species richness was significantly lower in acidic lakes than in circumneutral lakes ($P < 0.025$). Similarly, the Pearson correlation coefficient between species richness and lake pH revealed a positive relation between the two variables ($r = 0.68$, $P < 0.05$). These results are in contrast with those of Rahel and Magnuson [22], who studied fish communities in 19 small seepage, nonwinterkill dystrophic lakes in northern Wisconsin; their study lakes were physically similar but ranged in pH from 4.3 to 6.9, and no relation was found between species richness and pH.

Table IV. Numbers of Fish of Different Species Collected During Comprehensive Sampling of Fish Communities in 12 Northern Wisconsin Lakes (All Gear Types Combined)

	Acidic Lakes						*Circumneutral Lakes*					
Species	*Hilderbrand (5.1)*[a]	*Lumen (5.2)*	*Currie (5.6)*	*Zattle (5.6)*	*Flannery (5.7)*	*Clara (6.0)*	*Toulish (6.7)*	*Hixon (6.8)*	*Clear (6.9)*	*Dorothy Dunn (6.9)*	*Nelson (7.0)*	*Garth (7.5)*
Cisco	0	0	0	0	0	0	0	0	0	0	26	0
Central Mudminnow	0	0	0	0	0	0	0	0	0	1	1	0
Northern Pike	11	0	0	0	1	20	18	1	0	0	0	7
Muskellunge	0	0	0	0	0	0	0	0	0	11	0	0
Golden Shiner	0	2	2	0	0	0	0	18	0	9	0	8
Blackchin Shiner	0	0	0	0	0	0	0	0	0	0	20	0
Blacknose Shiner	0	0	0	0	0	0	32	0	0	0	129	0
Emerald Shiner	0	0	0	0	0	0	0	0	0	96	0	0
Weed Shiner	0	0	0	0	0	0	0	0	0	0	0	6
Bluntnose Minnow	0	0	0	0	0	0	354	264	1185	0	1032	1078
Creek Chub	0	0	1	0	0	0	0	0	0	0	0	0
White Sucker	6	1	217	15	2	0	2	4	44	17	12	0
Black Bullhead	8	7	0	0	0	0	0	0	9	0	0	5
Yellow Bullhead	0	0	0	0	116	178	4	91	19	2	1	70
Brook Stickleback	0	0	0	0	0	0	0	0	0	0	1	0
Rock Bass	0	118	9	303	0	0	45	2	0	0	153	2
Green Sunfish	0	0	34	0	52	0	0	0	0	0	0	0
Pumpkinseed	524	0	42	193	786	0	20	388	5	0	188	474
Bluegill	39	8624	176	0	474	792	636	816	171	127	981	1912
Smallmouth Bass	0	38	0	0	1	0	4	0	0	0	2	1
Largemouth Bass	43	145	119	56	8	44	58	65	23	183	45	112
Black Crappie	0	0	68	0	1	0	35	85	0	0	4	103
Iowa Darter	0	0	0	0	0	0	0	0	0	0	5	0
Johnny Darter	0	0	0	0	0	0	1	9	6	0	0	0
Yellow Perch	969	299	737	747	544	285	38	159	210	681	104	1030
Walleye	1	0	12	0	1	23	0	1	9	14	8	1
Mottled Sculpin	0	0	0	0	0	0	1	0	0	0	0	0
Total Number of Fish	1601	9234	1417	1314	1986	1342	1248	1903	1681	1141	2712	4809
Total Number of Species	8	8	11	5	11	6	14	13	10	10	17	14

[a] pH shown in parentheses.

Table V. Total Number of Fish of Different Families Collected During Sampling of Six Acidic and Six Circumneutral Lakes in Northern Wisconsin

	Lake Category	
Family	*Acidic*	*Circumneutral*
Salmonidae	0	26 (1)[a]
Umbridae	0	2 (1)
Esocidae	32 (1)	37 (2)
Cyprinidae	5 (2)	4,231 (6)
Catostomidae	241 (1)	79 (1)
Ictaluridae	309 (2)	201 (2)
Gasterosteidae	0	1 (1)
Centrarchidae	12,689 (7)	6,640 (6)
Percidae	3,618 (2)	2,276 (4)
Cottidae	0	1 (1)
Total	16,894 (15)	13,494 (25)

[a] Number of species represented in each family is given in parentheses.

More extensive analyses by Rahel [23] indicated that species richness in bog lakes is limited by habitat characteristics other than pH.

Minnows and darters, which are generally relatively sensitive to low pH [3], were either absent or rare in acidic lakes, but were generally well represented in the circumneutral lakes (Table VI). Only 5 minnows (two species) were found in the acidic lakes, whereas a total of 4231 minnows, representing six species, were found in the circumneutral lakes. Minnows were collected in only two acidic lakes, but were collected from all six circumneutral lakes (Table IV). The bluntnose minnow, a pH-sensitive species [3], occurred in five of the circumneutral lakes and was the most abundant cyprinid (Table VI). The only minnow species found in more than one of the acidic lakes (four individuals in two lakes) was the golden shiner, which is probably more acid-tolerant than the other minnow species collected [3]. In a survey of fish communities in northern Wisconsin lakes, Rahel [23] found that no cyprinid species occurred at $pH < 5.2$ and that darters and most cyprinids were absent at $pH < 6.2$. Four of the circumneutral lakes in the present study contained darters, but none were found in the acidic lakes (Table IV).

The number of fish species other than darters and minnows ranged from 5 to 11 in the acidic lakes and from 8 to 13 in the circumneutral lakes. A second Mann–Whitney test of species richness of fishes other than darters and minnows was conducted to determine if differences in species richness between the two groups of lakes were related primarily to the scarcity of darters and minnows in the acidic lakes. Species richness of fish species other than darters and minnows was also significantly less in the acidic than in the circumneutral lakes ($P < 0.05$).

No relation between species richness and lake area was apparent for the lakes studied here, probably because we selected lakes within a narrow size range

Table VI. Comparison of Total Number of Each Species Caught in Acidic and Circumneutral Lakes

Species	*Acidic Lakes* ($n = 6$)	*Circumneutral Lakes* ($n = 6$)
Cisco	0	26 (1)[a]
Central Mudminnow	0	2 (2)
Northern Pike	32 (3)	26 (3)
Muskellunge	0	11 (1)
Golden Shiner	4 (2)	35 (3)
Blackchin Shiner	0	20 (1)
Blacknose Shiner	0	161 (2)
Emerald Shiner	0	96 (1)
Weed Shiner	0	6 (1)
Bluntnose Minnow	0	3,913 (5)
Creek Chub	1 (1)	0
White Sucker	241 (5)	79 (5)
Black Bullhead	15 (2)	14 (2)
Yellow Bullhead	294 (2)	187 (6)
Brook Stickleback	0	1 (1)
Rock Bass	430 (3)	202 (4)
Green Sunfish	86 (2)	0
Pumpkinseed	1,545 (4)	1,075 (5)
Bluegill	10,105 (5)	4,643 (6)
Smallmouth Bass	39 (2)	7 (3)
Largemouth Bass	415 (6)	486 (6)
Black Crappie	69 (2)	227 (4)
Iowa Darter	0	5 (1)
Johnny Darter	0	16 (3)
Yellow Perch	3,581 (6)	2,222 (6)
Walleye	37 (4)	33 (5)
Mottled Sculpin	0	1 (1)

[a] The number of lakes in which each species was found is indicated in parentheses after each total.

and the number of lakes surveyed was not large (Table I). Pearson correlation coefficients between species richness and lake area, calculated for all lakes and for circumneutral lakes, were nonsignificant. However, a marginally significant correlation ($r = 0.77$, $0.05 < P < 0.10$) between lake area and species richness was observed for the six acidic lakes. Analysis of covariance of species richness between lake groups with lake area as a covariate yielded similar results; differences in mean species richness between acidic and circumneutral lakes were highly significant ($P < 0.005$), and lake area was not a significant factor ($P \sim 0.21$). Bounded plots of species richness against lake area showed virtually no overlap between acidic and circumneutral lakes (Figure 2).

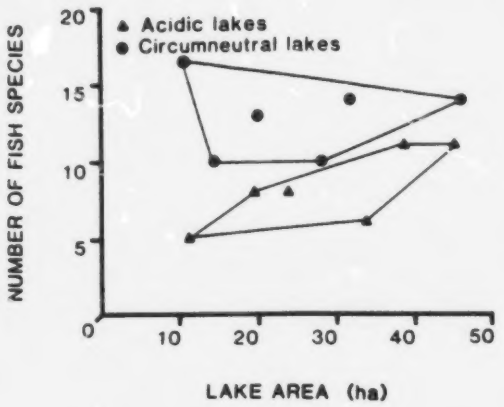

Figure 2. Relationship between number of fish species and surface area of acidic and circumneutral lakes in north-central Wisconsin. Points for each lake group were bounded to show separation between the two groups.

The occurrence of a fish species in one or two lakes of a given lake group could be attributed to chance rather than to suitability of the aquatic habitat for that species. Therefore, numbers of fish species in acidic and circumneutral lakes were compared according to frequency of occurrence within each lake group. Results of this comparison (Figure 3) indicated that common as well as rare species occurred less frequently in the acidic lakes than in the circumneutral ones. For example, only 8 species were found in three or more acidic lakes, whereas 14 species were found in three or more circumneutral lakes.

A total of 38 smallmouth bass were collected from Lumen Lake (Table IV), which had an autumnal pH of 5.2. Total lengths, measured for 21 of these fish, ranged from 96 to 228 mm (median, 119 mm). Externally visible deformities were not recorded for any of these specimens. Smallmouth bass is considered an acid-sensitive species, and reportedly is adversely affected at pH values of 5.5–6.0 or lower [1]. However, most investigators report pH values measured during summer, which are not directly comparable with the lake pH values given in Table I. The pH of northern Wisconsin lakes averages about 0.2 unit lower during autumn than during summer [24]. The pH of surface water from Lumen Lake during summer 1979 was 5.5, suggesting that the smallmouth bass population in Lumen Lake is near the lower range of pH tolerance for the species.

In a comparative field study of this type, it is not possible to state unequivocally that observed patterns are due solely to a single factor or group of related factors—in the present situation, water chemistry. There is, however, strong evidence suggesting that certain species should not occur in certain lakes, e.g., those in which

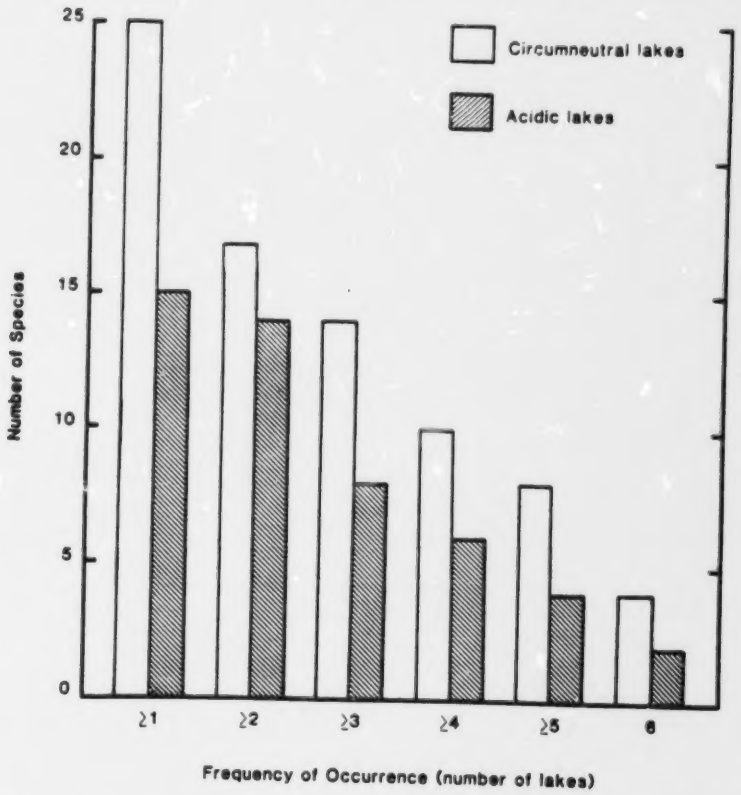

Figure 3. Number of fish species in the acidic and circumneutral lake groups as a function of frequency of occurrence in each group.

pH is below the presumed physiological tolerance range for the species in question [1,3]. Historical information on community composition of fishes in most of these lakes is scant or lacking. Hence, differences in community structure among lakes could be attributable to differences in initial colonizing populations or planned and accidental introductions. It is unlikely that the two groups of lakes studied here have dissimilar geologic histories relative to connection to other water bodies and consequently, to past migrations and invasions of fishes. All of the study lakes are glacial in origin from the same glacial lobe [25]. The acidic and circumneutral lakes are not greatly dissimilar with respect to glacial till, and the proximity of some of the acidic and circumneutral lakes (Figure 1) reduces the likelihood that the differences in fish communities between the two groups of lakes are due to some spatial factor.

It is also unlikely that the differences in fish community composition between the two groups of lakes are related to productivity. Limited data on chlorophyll-a concentrations, obtained during the summer 1979 survey of Eilers et al. [10], suggests that primary productivity does not differ greatly between the acidic and circumneutral lakes in this study. Chlorophyll-a in 2-m integrated surface water samples ranged from 1.84 to 3.91 $\mu g-L^{-}$ (average, 3.0 $\mu g-L^{-1}$ in the six acidic lakes and were 8.74 and 2.74 $\mu g-L^{-1}$, respectively, in two of the circumneutral lakes (Garth and Nelson Lakes).

The differences in the presence and abundance of cyprinids between the acidic and circumneutral lakes (Table V) are striking. Minnows are probably introduced frequently into lakes in this area by fishermen releasing bait fishes at day's end. We can offer no reason why such random introductions of minnows should be more frequent in the circumneutral than in the acidic lakes. In addition, no major differences in the presence of predatory fishes (northern pike, muskellunge, smallmouth and largemouth bass, black crappie and walleye) are readily apparent between acidic and circumneutral lakes (Table IV). We therefore conclude that the acidic lakes are unsuitable for most minnow species, because of pH-related water chemistry factors. This assertion is supported by published information on pH levels at which cyprinid species were adversely affected in both laboratory experiments and natural waters [1].

CONCLUSIONS

Fish communities in circumneutral Wisconsin lakes contained significantly more species than did those in acidic lakes (pH 5.1–6.0). Common as well as rare species occurred with lower frequency in acidic lakes than in circumneutral lakes. Certain taxa, such as minnows and darters, were either absent or rare in the acidic lakes, probably because of pH-related stress. The differences in species composition and richness of fish communities between acidic and circumneutral lakes did not appear to be related to differences in physical habitat characteristics, pas fish migrations or productivity between the two lake groups. Hydrogen ion concentration and related water chemistry characteristics strongly influence the species composition and richness of fish communities in lakes.

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